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HSI in the USN frigate community operational readiness and safety as a function of manning levels

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HSI IN THE USN FRIGATE COMMUNITY: OPERATIONAL READINESS AND SAFETY AS A FUNCTION OF MANNING LEVELS

by

Patrick C. Lazzaretti

December 2008

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Human Systems Integration (HSI) is a process designed to reduce life-cycle costs and improve system performance by considering human-related domains. Acquisition specialists lack objective, quantitative research findings on which to base trade-off analyses. This thesis used eight fiscal years of historical safety (mishaps), manpower (manning levels) and system performance (SORTS) data on the U.S. Navy's Frigates, collected from computer databases of routine reports, to explore relationships in an existing notional model of HSI. Three hypotheses were tested, there is a negative relationship between manning and SORTS levels, there is a negative relationship between manning and mishaps, and there is a positive relationship between mishaps and SORTS levels. No significant relationships were found between SORTS levels and manning or mishaps. When all of the ships were ranked for each month based on percent of total manning and number of reportable mishaps, a positive correlation (Spearman's rho = 0.4194, p-value = 0.0294) was found corresponding to a negative relationship between manning levels and mishap rates. More detailed research is needed to isolate the relationship between manning levels and mishap rates from numerous other influences and any noise that may be present in the data set.

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ABSTRACT

Human Systems Integration (HSI) is a process designed to reduce life-cycle costs and improve system performance by considering human-related domains. Acquisition specialists lack objective, quantitative research findings on which to base trade-off analyses. This thesis used eight fiscal years of historical safety (mishaps), manpower (manning levels) and system performance (SORTS) data on the U.S. Navy's Frigates, collected from computer databases of routine reports, to explore relationships in an existing notional model of HSI. Three hypotheses were tested: there is a negative relationship between manning and SORTS levels; there is a negative relationship between manning and mishaps; and there is a positive relationship between mishaps and SORTS levels. No significant relationships were found between SORTS levels and manning or mishaps. When all of the ships were ranked for each month based on percent of total manning and number of reportable mishaps, a positive correlation (Spearman's rho = 0.4194, p-value = 0.0294) was found corresponding to a negative relationship between manning levels and mishap rates. More detailed research is needed to isolate the relationship between manning levels and mishap rates from numerous other influences and any noise that may be present in the data set.

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EXECUTIVE SUMMARY

Human Systems Integration (HSI) is a process designed to reduce life-cycle costs and improve system performance by considering human-related domains. All Department of Defense (DoD) acquisition programs are required to consider HSI. The Navy's HSI guidance includes modernization programs of legacy systems. However, acquisition specialists lack objective, quantitative research findings on which to base trade-off analyses for developmental or legacy systems.

This thesis used eight fiscal years of historical safety (mishaps), manpower (manning levels) and system performance (SORTS) data on the U.S. Navy's Oliver Hazard Perry (FFG-7) Class Frigates, collected from computer databases of routine reports, to explore relationships in an existing notional model of HSI. The three hypotheses tested were, there is a negative relationship between manning and SORTS levels, there is a negative relationship between manning and mishaps, and there is a positive relationship between mishaps and SORTS levels.

No significant relationships were found between SORTS levels and manning or mishaps. When all of the ships were ranked from 1 (best), to 27 (worst), for each month of the study period based on percent of total manning and number of reportable mishaps, a positive correlation (Spearman's rho = 0.4194, p-value = 0.0294) was found corresponding to a negative relationship between manning levels and mishap rates.

No practically significant differences were found in manning, personnel, performance or safety based on date, ships, homeport, or region. This means that data collected on a sample of ships should be applicable to all Navy Frigates. However, there were significant differences found in manning levels between the Navy Reserve ships and active component ships.

The data analyzed for this thesis were insufficient to validate all the relationships in NPS's notional HSI trade space tool and more detailed research is needed to isolate the relationship between manning levels and mishap rates from numerous other influences and any noise that may be present in the data set.

HSI, though required by law, is often confused as just HFE or just SE. There remains a need for shared representations of the HSI trade space to facilitate communication between what are often isolated domains. While the data collected for this thesis were insufficient to validate all the relationships in one notional trade space tool, finding a negative relationship between manning and mishap rates is a substantial step forward. Just as this thesis advanced previous work, further research is still needed to fully develop NPS's HSI TST to maturity.

LIST OF ACRONYMS and ABBREVIATIONS

Anti-Air Warfare (AAW)

Capability Development Document (CDD)

Capability Production Document (CPD)

Category Five (C-5)

Category One (C-1)

Chairman, Joint Chiefs of Staff Instruction (CJCSI)

Chairman, Joint Chiefs of Staff Manual (CJCSM)

Chief of Naval Operations Instruction (OPNAVINST)

Chief Petty Officers (CPOs)

Class Squadron (CLASSRON)

Commander, Military Sealift Command Instruction (COMMSCINST)

Commander, Naval Surface Forces, Pacific (CNSP)

Crew Resource Management (CRM)

Cruisers and Destroyers (CRUDES)

Data Request System (DRS)

Defense Acquisition Guidebook (DAG)

Defense Manpower Data Center (DMDC)

Department of Defense (DoD)

Department of Defense Directive (DoDD)

Department of Defense Instruction (DoDI)

Department of the Navy (DON)

Destroyer (DD)

Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF)

Enlisted Data Verification Report (EDVR)

Environmental Safety and Occupational Health (ESOH)

Federal Aviation Administration (FAA)

Federation of American Scientists (FAS)

Fiscal Year (FY)

Guided Missile Frigate (FFG)

Hazard Report (HAZREP)

Human Systems Integration (HSI)

Human Factors Engineering (HFE)

Information Technology (IT)

Initial Capabilities Document (ICD)

Joint Capabilities Integration and Development System (JCIDS)

Major Automated Information System (MAIS)

Major Defense Acquisition Program (MDAP)

Manpower and Personnel Integration (MANPRINT)

Manpower, Personnel, and Training (MPT)

Marine Accident Investigation Branch (MAIB)

Military Analysis Network (MAN)

Multi-Attribute Utility Theory (MAUT)

National Aeronautical and Space Agency (NASA)

Naval Center for Cost Analysis (NCCA)

Naval Manpower Analysis Center (NAVMAC)

Naval Postgraduate School (NPS)

Naval Sea Systems Command (NAVSEA)

Navy Enlisted Classification (NEC)

Navy Personnel Command (NPC)

Office of Continuous Learning (OCL)

Outside the Continental United States (OCONUS)

Planning, Programming, Budgeting and Execution (PPBE)

Program Budget Information System (PBIS)

Secretary of the Navy (SECNAV)

Ship Manpower Document (SMD)

Status of Resources and Training System (SORTS)

Systems Engineering (SE)

Trade-Space Tool (TST)

Unit Identification Code (UIC)

United States (U.S.)

United States Navy (USN).

United States Navy Oliver Hazard Perry Class Frigate (FFG-7)

United States Naval Reserve (USNR)

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I. INTRODUCTION

The stated goal of Human Systems Integration (HSI) is to reduce life-cycle costs and improve system performance by considering human-related domains. All Department of Defense (DoD) acquisition programs are required to consider HSI. However, there is a dearth of evidence to define relationships among domains. This thesis is the first empirical exploration of the relationships between HSI domains and system performance, based on historical data.

A. HISTORY OF HUMAN SYSTEMS INTEGRATION (HSI)

The DoD defines HSI as a process designed to "optimize total system performance, minimize total ownership costs, and ensure that the system is built to accommodate the characteristics of the user population that will operate, maintain, and support the system" (Department of Defense Instruction [DoDI] 5000.2, 2004, p. E7-1). HSI encompasses seven distinct domains: human factors engineering (HFE), personnel, habitability, manpower, training, environmental safety and occupational health (ESOH), and survivability (DoDI 5000.2, 2004).

At the most basic level, human considerations are as old as tool making; older than civilization itself. Human-centered design considerations have been around since the first humanoid chose which rock to shape into a hand ax. Over the centuries, systems became more complex and mass production replaced custom production, increasing the challenge of designing systems to accommodate human users.

All of the individual domains of HSI predate the formation of HSI as a discipline. Academic books on the subject describe HFE as the initial domain of HSI. The addition of the other domains, and the consideration of the interactions between the domains, produces the HSI process. Research into pilot error in World War II was instrumental in formalizing work in HFE into a discipline (Pew & Mavor, 2007; Simpson, 2003). In the foreword to the *Handbook of Human*

Systems Integration, Booher describes HSI as the third milestone of human-focused considerations within the U.S. Defense community. He lists the first milestone as the development of HFE and the second milestone as implementation of the U.S. Army's Manpower and Personnel Integration (MANPRINT) program (Booher, 2003).

B. RATIONALE FOR THE STUDY

1. The Human Systems Integration (HSI) Mandate

In 2003, the United States Congress, through Department of Defense Directive (DoDD) 5000.1, mandated the inclusion of HSI in all DoD acquisition programs. The primary sources of HSI requirements are *The Defense Acquisition System*, DoDD 5000.1, and *Operations of the Defense Acquisition System*, DoDI 5000.2. Chapter Six of the *Defense Acquisition Guidebook* (DAG) provides nonbinding guidance on implementing the mandates in DoDD 5000.1 and DoDI 5000.2.

The most cost effective way to implement the congressional mandate is to consider HSI trade-offs from the beginning of the acquisition process. However, acquisition specialists lack objective, quantitative research findings on which to base trade-off analyses for developmental or legacy systems.

2. Human Systems Integration (HSI) in Legacy Systems

DoDD 5000.1 applies to all New DoD acquisition programs (DoDD 5000.1, 2007). Secretary of the Navy (SECNAV) Instruction 5000.2C and Naval Sea Systems Command (NAVSEA) Instruction 3900.8A expand the applicability of HSI to include modernization, disposal, and demilitarization of new and existing programs. Both of these Navy instructions recognize the need for HSI to evaluate alterations to legacy systems. Navy ships are not static objects; they are large and complex systems of systems, operating in a dynamic global environment. Predictions are that in the next ten years, "HSI personnel will become the experts

in issue tracking and resolution as systems are now never finished" (Pew & Mavor, 2007, p. 286). Currently, program managers struggle to predict and plan for HSI-related considerations (total life-cycle costs, utilization, operational environment) in the initial acquisition process. This thesis seeks to further develop a model that can evaluate the impact of alterations to developmental and legacy programs. Alterations to legacy programs could include any or all of the doctrine, organization, training, materiel, leadership and education, personnel, and facilities (DOTMLPF) factors.

The absence of attention to HSI throughout the full life cycle is likely due to the argument of a low return on investment. Changes and improvements in legacy systems are severely constrained by the existing HFE level. For example, HFE, through physical space and acceptable habitability levels, sets the upper limit of manning on a ship. Lower limits are set through the tasks (manpower) and skills (personnel) needed to operate the ship. This leaves HFE and training as the primary avenues to alter a system's manpower, personnel, habitability, safety, and survivability. Compared to the initial concept development of a novel system, legacy systems have a restricted trade space and higher cost for marginal improvements.

The low-return-on-investment argument overlooks two opportunities. Since DoD systems are large, complex, and operate in a dynamic environment, they change constantly. Using HSI will improve the quality of modernization efforts. Second, identifying and capturing lessons learned, even those not cost effective to fix in the current system, will improve future systems under development. In addition to evaluating initial design decisions of legacy systems, program managers would benefit from careful studies of how systems evolve and operate.

C. OBJECTIVE

1. Scope

This thesis seeks to explore relationships among HSI domains. A subset of the relationships from the Naval Postgraduate School's (NPS) Trade-Space Tool (TST) is studied, using a retrospective analysis of historical data. This thesis is built on a theoretical foundation laid by an NPS thesis, "Toward an Improved Method of HSI Evaluation in Defense Acquisition" (Simpson, 2006). The fleet of U.S. Navy Frigates served as a proof of concept to explore the relationships among HSI domains.

2. Limitations

This thesis focused on a single class of ship in an effort to improve accuracy at the expense of generalization to other platforms. The U.S. Navy's Oliver Hazard Perry Class Frigate (FFG-7) is an ideal initial platform to analyze for several reasons. It is the smallest and simplest ship in the cruiser and destroyer (CRUDES) class. The decision to focus on the U.S. Navy Frigate simplified the amount of data to gather, encode, and analyze. Two of the four surface ship classes currently in development are in the CRUDES class—the Littoral Combat Ship and the next generation Destroyer. Minesweepers and patrol craft, though smaller and simpler systems, might not provide as much insight into these current systems under development.

The data collected were limited to measures available on computer databases from routine reports. This study did not attempt to collect data from the ships directly, but instead relied on data already stored in a variety of repositories. The complexity of the problem space necessitated numerous simplifications. Many of the terms used in DoDD 5000.1 are vague and context related, making them challenging to measure. Chapter III, Section G of this thesis details how the variables of manpower, HFE, habitability, survivability, safety, and performance were quantified for the purposes of this thesis effort.

II. LITERATURE REVIEW

A. OVERVIEW

This chapter provides a general overview of the HSI literature. Sections B and C discuss the chain of guidance, in the order of precedence, that applies to the United States Navy. This chain of guidance represents just one of many document chains branching off the DoD HSI guidance. Section D discusses and summarizes two books on HSI. Section E concludes the HSI literature review with a summary of how all the sections build a picture of the current state of HSI within the DoD. Section F highlights the relationships among the HSI domains, with a focus on safety. Section G introduces NPS's concept of HSI. Section H describes the two of the three data sources used in this thesis: the official U.S. Navy mishap reports and Status of Resources and Training System (SORTS) reports.

B. DEPARTMENT OF DEFENSE (DoD) HSI GUIDANCE

DoDD 5000.1, *The Defense Acquisition System*, and DoDI 5000.2, *Operation of the Defense Acquisition System*, reference each other and together provide the superseding guidance for all DoD acquisition programs. The *Defense Acquisition Guidebook* (DAG) contains suggestions and recommended best practices for implementing DoDD 5000.1 and DoDI 5000.2 (DAU Website, 2004). The Chairman, Joint Chiefs of Staff Instruction (CJCSI) 3170.01F and the Chairman, Joint Chiefs of Staff Manual (CJCSM) 3170.01C provide guidance for Joint Capabilities Integration and Development System (JCIDS) acquisition programs (CJCSI 3170.01F, 2007, CJCSM 3170.01C, 2007).

1. Department of Defense Directive (DoDD) 5000.1

DoDD 5000.1, Section 1.2 states, "This directive, along with reference (b) [DoDI 5000.2], provides management principles and mandatory policies and

procedures for managing all acquisition programs" (DoDD 5000.1, 2003, p. 2). Section 2, Applicability and Scope, states that the DoDD 5000.1 applies to all acquisition programs within the Defense Department.

The only direct reference to HSI is Enclosure 1.29, Total Systems Approach, which directs program managers to "apply human systems integration to optimize total system performance (hardware, software, and human), operational effectiveness, and suitability, survivability, safety, and affordability" (DoDD 5000.1, 2003, p. E1-29). Enclosure 1.29 goes on to stress total ownership and life-cycle considerations. When viewed online, the words "human system integration" hyperlink to Chapter 6 of the DAG.

2. Department of Defense Instruction (DoDI) 5000.2

The DoDI 5000.2 purpose section states, "This instruction: implements reference (c) [DoDD 5000.1], the guidelines of references (d) and (e), and current laws" (DoDI 5000.2, 2003, p. 2). DoDI 5000.2 has the same applicability as DoDD 5000.1, to all DoD acquisition programs, with the additional guidance that some requirements only apply to Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) programs (DoDI 5000.2, 2003).

Enclosure 7, Human Systems Integration (HSI), directs the program manager to

> . . . have a comprehensive plan for HSI in place early in the acquisition process to optimize total system performance, minimize total ownership costs, and ensure that the system is built to accommodate the characteristics of the user population that will operate, maintain, and support the system. (DoDI 5000.2, 2003, p. E7)

The enclosure then lists seven HSI domains, with direction on how the program managers are to address each one. DoDI 5000.2, Enclosure 7, is

included as Appendix B of this thesis. Although it implies the need to make trade-offs, DoDI 5000.2 does not direct how to “optimize performance” to “minimize total ownership costs.”

In addition to Enclosure 7, Section 3.7.1.1 mentions HSI as one of a dozen considerations during the system development and demonstration phase. Section 3.9.2.2, under Sustainment, does not mention HSI by name, but does direct program managers to consider the HSI domains of manpower, personnel, training, HFE, habitability, environmental, safety, and occupational health (ESOH), and survivability.

3. Defense Acquisition Guidebook (DAG)

The DAG is an online document

> designed to complement [the DoDD 5000.1 and the DoDI 5000.2] by providing the acquisition workforce with discretionary best practice that should be tailored to the needs of each program . . . . All chapters contain non-mandatory staff expectations for satisfying the mandatory requirements in DoD Instruction 5000.2. (DAG, 2004, ¶ foreword)

Chapter 6 of the DAG is the primary source of high-level guidance on HSI. The overview states, “DoD acquisition policy [DoDD 5000.1] requires optimizing total system performance and minimizing the cost of ownership through a ‘total system approach’ to acquisition management” (DAG, 2004, ¶ 6.0). Section 6.0.1, Purpose, defines HSI as an element of the systems engineering process, whose understanding will allow Program Managers to effectively and affordably integrate human capabilities and limitations in system design and development (DAG, 2004).

Chapter 6 has six subsections. Section 6.1, Total System Approach, briefly reviews DoDD 5000.1 directed total system approach. It highlights the need to consider maintenance, support, and training as parts of the total system. Section 6.2 has seven subsections, each one describing an HSI domain.

Section 6.3 provides planning details for the HFE domain. Section 6.4 provides advice on HSI implementation. Section 6.5 describes the human considerations associated with resource estimating and planning. The last section of Chapter 6, Section 6.6, provides two reference listings for additional information (DAG, 2004).

Section 6.4 articulates a vision of what HSI is and, in general, how to conduct it.

> The key to a successful HSI strategy is integration. To optimize total system performance and determine the most effective, efficient, and affordable design entails trade studies both within the HSI elements and between the HSI elements and the system platform. (DAG, 2004, ¶ 6.4)

It goes on to recommend that Program Managers integrate HSI parameters/requirements in the Initial Capabilities Document (ICD), Capability Development Document (CDD), and Capability Production Document (CPD). In addition to Chapter 6, recommendations to apply HSI appear throughout the DAG, from initial capabilities through final test and evaluation to life-cycle logistics.

4. Chairman, Joint Chiefs of Staff Instruction (CJCSI) 3170.01 Series

The CJCSI 3170.01F, *Joint Capabilities Integration and Development System*, is a 59-page document that establishes the policies and procedures of the JCIDS (CJCSI 3170.01F, 2007). The instruction mentions HSI only five times—twice in Enclosure B, Policy, and three times in the Glossary. Enclosure B states:

> DOTMLPF [doctrine, organization, training, materiel, leadership and education, personnel, and facilities] includes analysis of the entire life cycle, including the sustainment; environment, safety, and occupational health (ESOH); and all human systems integration (HSI) domains. (CJCSI 3170.01F, 2007, p. B-1)

Later, Enclosure B mentions HSI as one consideration when identifying capability gaps and potential materiel and nonmaterial solutions (CJCSI 3170.01F, 2007). The Glossary definition of HSI references DoDI 5000.2 and adds that it includes the integrated and comprehensive analysis, design, and assessment of requirements, concepts, and resources for system manpower, personnel, training, safety and occupational health, habitability, personnel survivability, and HFE. The Glossary definition of “nonmaterial solutions” refers to HSI under policy changes. The Glossary also lists HSI as a consideration for “supportability” (CJCSI 3170.01F, 2007).

5. Chairman, Joint Chiefs of Staff Manual (CJCSM) 3170.01 Series

CJCSM 3170.01C, *Operation of the Joint Capabilities Integration and Development System*, is a 149-page document that

> . . . sets forth guidelines and procedures for operation of the Joint Capabilities Integration and Development System (JCIDS) regarding the development and staffing of JCIDS documents in support of reference (a) [CJCSI 3170.01 series]. (CJCSM 3170.01.C, 2007, p. 1)

Appendix A to Enclosure E, Capability Development Document Format, and Appendix A to Enclosure F, Capability Production Document Format, each mention HSI twice. Under “Other DOTMLPF and Policy Considerations,” it advises discussion of HSI considerations that have a major impact on system effectiveness, suitability, and affordability. Under “Other System Attributes,” it mentions HSI as one factor to “consider as appropriate” (CJCSM 3170.01C, 2007).

6. Conclusions on Department of Defense (DoD) Guidance

The DoD instructions are high-level and broad. While the DAG provides excellent advice, it is nonbinding. The CJCSI and CJCSM mention HSI as a consideration, but do not define it or provide direction about how to employ it.

C. UNITED STATES NAVY HUMAN SYSTEMS INTEGRATION (HSI) GUIDANCE

This section looks at the chain of instructions that pertain to the implementation of HSI for U.S. Navy systems. These instructions provide clarification and further guidance to the DoD and CJCS guidance already discussed. This section presents the instructions by order of precedence, from highest to lowest. At each level, the documents provide requirements in addition to the requirements in the documents they reference.

1. Secretary of the Navy (SECNAV) Instruction 5000.2 Series

SECNAV Instruction 5000.2D, *Implementation and Operation of the Defense Acquisition System and the Joint Capabilities Integration and Development System*, is a 195-page instruction that includes guidance for HSI. It issues requirements for major and nonmajor defense acquisition and information technology programs for the Department of the Navy (DON) (SECNAV 5000.2D, 2008). It also cites the DAG as a discretionary companion to the instruction.

Section 1.7.k, under Responsibilities, identifies the Director, Total Force Requirements Division, (CNO [N12]), as the single governing authority for HSI policy, requirements, and resources. The N12 is directed to participate in the identification of enterprise Manpower, Personnel, Training (MPT) and education shortfalls, and to investigate innovative approaches and solutions to optimize manpower and improve performance (SECNAV 5000.2D, 2008).

The primary HSI guidance in SECNAV 5000.2D is in Enclosure 7, Systems Engineering and Human Systems Integration. It directs program managers to include HSI in a systems engineering process used to translate operational requirements/capability needs into a system solution (SECNAV 5000.2D, 2008). Section 7.1.6.2, explicitly directs information technology (IT) systems to address interoperability and HSI considerations (SECNAV 5000.2D,

2008). Section 7.2.1, HSI in Acquisition, specifically addresses HSI and defines the scope of acquisition programs, to include modifications to legacy systems (SECNAV 5000.2D, 2008).

Sections 7.2.2 through 7.2.5 of SECNAV 5000.2D provide one paragraph each on how to consider the HSI domains. Section 7.2.2 lists MPT as a single factor. The other three sections are 7.2.3, HFE; 7.2.4, Personnel Survivability; and 7.2.5, Habitability. Section 7.3 addresses Environmental, Safety, and Occupational Health (ESOH) considerations and is seven pages long, including two full-page tables (SECNAV 5000.2D, 2008).

HSI is briefly mentioned in Section 2.1.2.3 under the discussion of manpower requirements.

> DOTMLPF analyses, conducted as the first step in the Functional Solutions Analysis, shall address all eight Human Systems Integration (HSI) domains including Environmental, Safety, and Occupational Health (ESOH). (SECNAV 5000.2D, 2008, p. E2-10)

Section 3.4 is Acquisition Strategy. Section 3.4.7.1, Human Systems Integration (HSI), mandates an acquisition strategy that summarizes HSI planning, including how the program will meet HSI program requirements and standards (SECNAV 5000.2D, 2008).

2. Chief of Naval Operations Instruction 5310.23 Series

OPNAVINST 5310.23 is currently in draft format. If signed, it will reference SECNAVINST 5000.2D and will replace reference (a), Chief of Naval Operations Guidance for 2004, of the Naval Sea Systems Command (NAVSEA) Instruction 3900.8 Series.

3. Naval Sea Systems Command (NAVSEA) Instruction 3900.8 Series

NAVSEA Instruction 3900.8A is Human System Integration (HSI) Policy in Acquisition and Modernization Programs (NAVSEA 3900.8A, 2005). This

16-page document expands the definition of acquisition programs to include research and development, modernization, and disposal programs.

Section 6 of NAVSEA 3900.8A, Responsibilities, outlines the roles and tasks for each level from the NAVSEA 03 to Ship Design Managers. Section 6 directs NAVSEA Deputy Commanders to “ensure manpower and training trade-offs studies are conducted and documented . . . to minimize manning and training costs” (NAVSEA 3900.8A, 2005, p. 4).

Enclosure 1 provides the first detailed guidance on how to develop and implement an HSI plan. Enclosure 1 explicitly states that an interdependent relationship exists between the HSI domains, and trade-offs made in a program can have an impact across all of the domains. It mandates the development of HSI criteria for all programs. Enclosure 1 cites 20 instructions and industry standards as references to assist in developing and evaluating HSI trade-offs.

4. Conclusions on United States Navy Human Systems Integration (HSI) Guidance

The Navy’s HSI guidance expands the scope to include modernization programs of legacy systems. Of all the DoD and U.S. Navy instructions reviewed, NAVSEA 3900.8A is the only one that mentions trade-offs across all domains.

D. ACADEMIC HUMAN SYSTEMS INTEGRATION (HSI) GUIDANCE

1. Handbook of Human Systems Integration (HSI)

The *Handbook of Human Systems Integration* (Booher, 2003) is a 965-page tome containing the most extensive guidance available on HSI. It is the collected work of approximately 90 contributors, technical advisors, and reviewers from the government, industry, and academia. Contributors reported the status of HSI in the United Kingdom, Canada, the United States Army, the United States Navy, the United States Air Force, the Federal Aviation

Administration, and the National Academy of Sciences. Many of the chapters cover both military and nonmilitary applications (Booher, 2003).

Section 1.2.1 defines HSI as primarily a technical and managerial concept, with specific emphasis on methods and technologies that can be utilized to apply the HSI concept to systems integration (Booher, 2003). This circular definition is followed by a section that quotes the U.S. Army's Manpower and Personnel Integration (MANPRINT) and DoDI 5000.2 definitions of the "HSI concept." The preface describes HSI as a very attractive new integrating discipline that can help move business and engineering cultures toward a people-technology orientation (Booher, 2003).

In the HSI Handbook, Booher describes HSI as an addition to the systems engineering (SE) process. The book cautions,

> If organizations are to change significantly to take full advantage of the benefits that HSI can offer, I [Booher] believe this is most likely to be accomplished as an inherent part of systems engineering and management. (Booher, 2003, p. xvi)

Though HSI developed from previous HFE and SE work, it is more than just HFE or "good" systems engineering. Booher states in the foreword:

> Human factors and ergonomics, while important components are not themselves sufficient because they do not cover other important human domains . . . . The major component currently missing from systems engineering and management is a detailed description of the principles and methods of human systems. The intent of the Handbook is to provide that component. (Booher, 2003, p. xvi)

Acknowledging the broad scope of HSI and the diversity of contributors, the handbook is designed to help users identify the sections of most interest to them. The chapters are grouped into sections and each section and chapter start with an overview (Booher, 2003). The chapters that are most relevant to this thesis are Chapters 8 and 17, which address interactions and trade-offs between all of the domains.

Chapter 8, written by Barnes and Beevis, starts by citing the DoD direction for HSI in military systems. It discusses human performance measurement issues related to system design, with a focus on those issues that require trade-offs. When discussing the development process Barnes and Beevis state,

> Since a single model or simulation that is in any sense complete is usually not available early in the design process, the HSI practitioner must rely on a combination of modeling, human experimentation, and simulation for each stage of development. (Booher, 2003, p. 237)

In Section 8.7, Interactions Among HSI Domains, Barnes and Beevis add that when planning human performance measures for a system under development, it is important to remember that the various HSI domains are interrelated and that changes in design to improve one domain nearly always affect other domains (Booher, 2003). Supporting the present study they note that, “Although the need is obviously great, there is no well-established body of knowledge on HSI domain trade-offs” (Booher, 2003, p. 254).

Chapter 17, by Rouse and Boff, addresses types of HSI investments that have intangible characteristics in addition to more tangible attributes. For example, investing in more training or higher personnel selection standards can result in less health and safety costs and higher morale and productivity. Rouse and Boff also note the difficulty in balancing trade-offs between short-term and long-term benefits (Booher, 2003).

Chapter 17 recommends using a multiattribute utility theory (MAUT) model to allow each stakeholder to assign “costs” and “benefit” values to each system attribute and time. This allows for quantitative weights of qualitative things, making assumptions explicit and open to testing. Rouse and Boff found that use of the MAUT methodology documents underlying assumptions, making them explicit and open to review (Booher, 2003). Quantifying and comparing utility inputs can be difficult with large numbers of variables. Evaluating costs and

benefits is further complicated by investment costs spread over time, uncertain returns, multiple stakeholders with different values, and indirect and intangible returns.

2. Human-System Integration (HSI) in the System Development Process: A New Look

The United States Army and United States Air Force funded this 384-page report by the National Academy of Science's Committee on Human-System Design Support for Changing Technology. The introduction defines HSI as a discipline concerned with ensuring that the characteristics of people are considered throughout the system development process, with regard to their selection and training, their participation in system operation, and their health and safety (Pew & Mavor, 2007).

The authors propose a "risk-driven" approach that achieves cost effectiveness by focusing resources on high-risk aspects of a program, while deemphasizing resources spent on low-risk aspects (Pew & Mavor, 2007). The focus of this book is similar to the focus of Chapter 17 of the *Handbook of Human Systems Integration.* This book differs from Chapter 17 of the Handbook of HSI with respect to benefit considerations. Pew and Mavor contend that HSI risk trade-offs must be presented in terms of acquisition and life-cycle costs and benefits, as opposed to including intangible benefits (Pew & Mavor, 2007). They agree with Chapter 17 of the Handbook of HSI on the need for a "shared representation" that can make assumptions explicit and open to review (Pew & Mavor, 2007).

In addition to supporting the present work in trade space development, this book reinforced the past choices and influenced the current choices of variables. In the conclusions to one of their examples, they noted that HFE concerns are often linked to MPT concerns (Pew & Mavor, 2007). This supports

the first design of the NPS trade space by Simpson (2006), with MPT and HFE as inputs that determine the levels of performance, risk, and the other HSI domains.

The book defines two different types of risk: operational risk and program risk. Figure 1 outlines the types of risk.

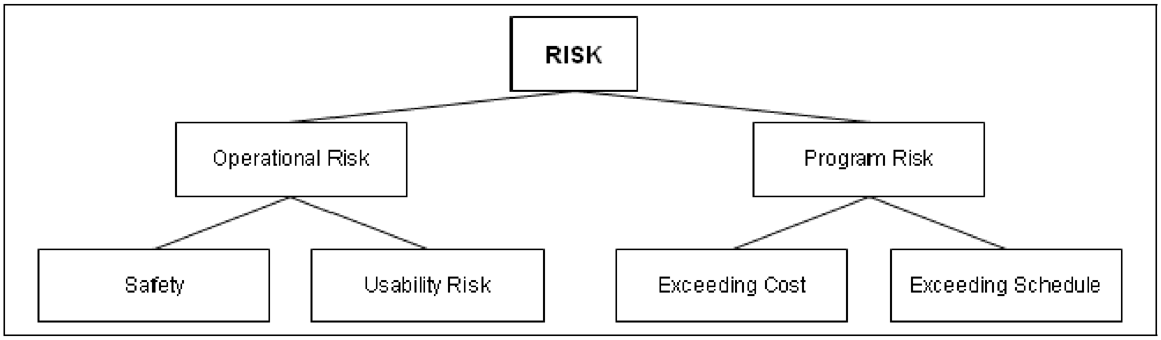

Figure 1. Taxonomy of Risk

The book defines operational risk as safety and usability risk. Safety is the risk that users will cause damage or be injured while using the item. Usability risk is the risk that operators will not use the item fully or at all. Program management risk is the risk of exceeding budgeted cost and the risk of exceeding allotted schedule (Pew & Mavor, 2007).

E. HUMAN SYSTEMS INTEGRATION (HSI) CONCLUSIONS

One obstacle to effective HSI in DoD programs is the long-term and uncertain nature of life-cycle costs. While the literature suggests that HSI should consider operational risks and life-cycle costs, current DoD and Navy instructions only apply to the acquisition process, which evaluates performance based predominately on short-term program risk. The other main obstacle is that, despite discussions of the interconnections between the domains, the HSI literature focuses primarily on the individual domains of HSI. DoD instructions discuss HFE and ESOH separately from the other domains, while MPT tend to be grouped together.

Several factors propagate this condition. All of the HSI domains, with the exception of system survivability, are stand-alone fields that predate HSI. Most HSI practitioners have education and background in only one or two of the HSI domains. In DoD and private industry, HSI domains are often separate functional areas in different parts of the organizations. All of these factors highlight the need for “shared representations” that can take inputs from experts in one domain, and display and translate them into effects on the other domains and on total system performance.

F. SAFETY LITERATURE

Safety considerations have traditionally been one of the largest drivers in HSI trade-offs. As seen in the DoD and U.S. Navy instructions reviewed previously, safety is often discussed separately and often in greater detail than the other HSI domains. This is not surprising, as it was the cost of airplane mishaps during World War II that formalized HFE, a primary domain of HSI, into a discipline. Therefore, an evaluation of safety literature from the United States Navy and civilian industries is relevant to this thesis.

A 2004 study by the Marine Accident Investigation Branch (MAIB) of the United Kingdom looked at 66 mishaps of merchant vessels operating near the coast of the British Isles. The study determined that having only two watch standers taking turns led to fatigue and inadequate performance. It recommended adding a third person to the rotation and having a lookout in all but clear weather with light traffic (MAIB, 2004). The larger watch team size of Navy ships does not prevent similar mishaps. In an opinion piece from *Fathom* magazine, Rear Admiral Finney discussed two almost identical collisions, each between a Navy destroyer (DD) and a merchant ship, in the same shipping channel, 30 months apart. He notes that, in both cases, the crew failed to follow established procedures, failed to communicate, and lookouts were missing required equipment (Finney, 1992).

Thus, while manning levels and personnel are factors in mishap rates, as the size of the crew increases, manning and personnel factors have less influence than factors such as team performance and workload. An investigation of manning onboard 18 U.S. Navy ships by the Naval Health Research Center found that manpower utilization had a stronger relationship with performance and illness levels than did the manning level (Dean, Harvey, Pugh, & Gunderson, 1979).

As another example, research efforts by National Aeronautical and Space Agency (NASA) and the Federal Aviation Administration (FAA) in the late 1970s found that human error and teamwork failures, and not mechanical malfunction, were the major causes of industrial accidents. This led to the development of Crew Resource Management (CRM) training programs by commercial airlines. CRM programs teach nontechnical skills, such as teamwork and communication, to improve operational performance. Training programs include both initial training and regular refresher training. In addition to its current use by all major international airlines, the CRM concept is applied in military aviation, anesthesiology, air traffic control, the Merchant Navy, the nuclear power industry, aviation maintenance, and the offshore oil industry (Flin, O'Connor, & Mearns, 2002).

G. NPS HUMAN SYSTEMS INTEGRATION (HSI) CONCEPT

This thesis builds on a theoretical framework proposed in an NPS thesis, "Toward an Improved Method of HSI Evaluation in Defense Acquisition" (Simpson, 2006). The previous thesis proposed a model for an HSI trade space tool (TST) with four input variables and four output measures. Manpower, personnel, training, and HFE are the four input variables; the remaining HSI domains are functions of the interactions of the inputs and the output is total system performance.

The model represented in Figure 2 looks at how total system performance is determined by inputs of MPT and HFE with enabling/constraining factors of

cost, schedule, and risk. The final outcome, total system performance, is the combination of all of the first order outcomes, which includes mishap rates (Miller & Shattuck, 2007).

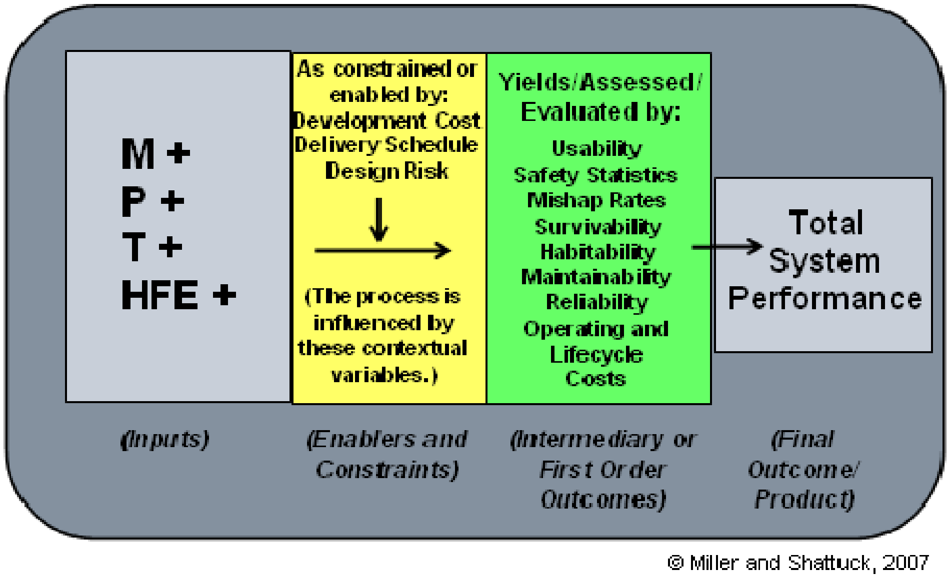

Figure 2. NPS HSI Process Model (From Miller & Shattuck, 2007)

From this model, a tradespace tool (TST) was developed by the NPS Office of Continuous Learning (OCL). The initial version of the TST was developed during thesis efforts by Simpson (2006). Figures 3 and 4 show the input screens for the NPS HSI TST.

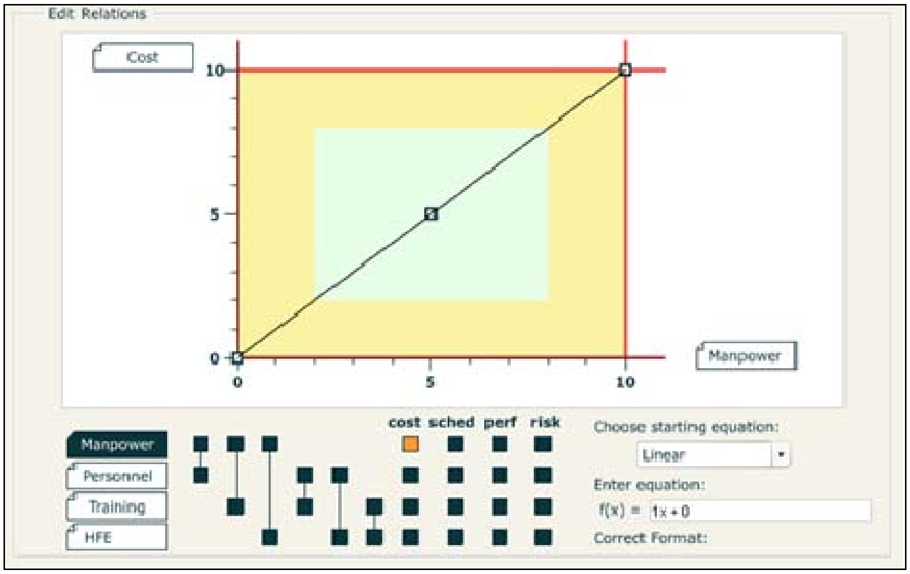

Figure 3. NPS HSI TST Input Screen

The user defined the relationships between four variables with each other, and with the acquisition variables of cost, schedule, performance, and risk. Once these 22 interactions were defined, the user progressed to a second screen, shown in Figure 4. This screen contained eight slider bars, four for the input variables and four for the output variables. Moving any one of the input slider bars shifted all four of the output bars according to the defined relationships.

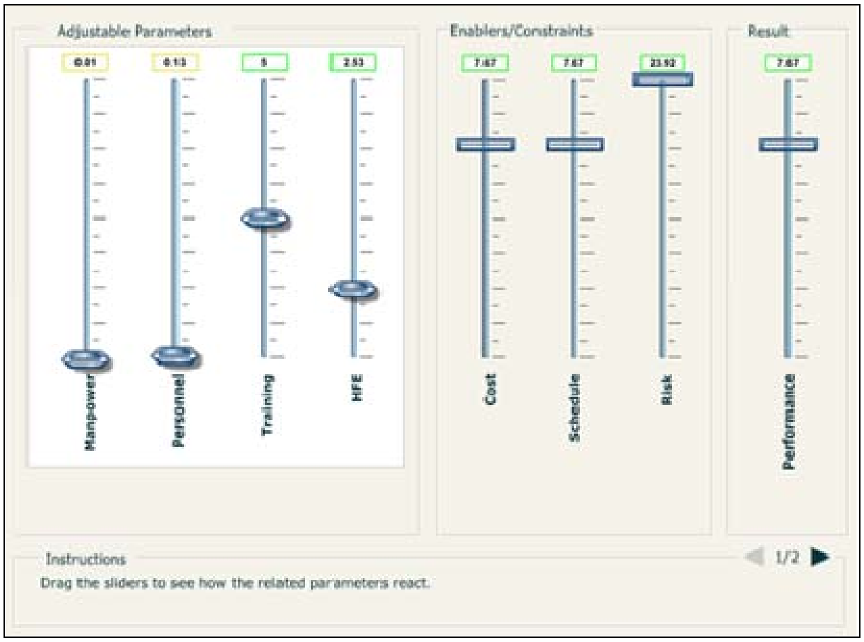

Figure 4. NPS HSI TST Results Screen

H. NAVY REPORT FORMATS

This section describes the format for the two data sets collected, U.S. Naval Safety Center Mishap Reports and SORTS reports.

1. Naval Safety Center Mishap Reports

The Chief of Naval Operations Instruction (OPNAVINST) 5102.1D (2005) defines Class A, B, and C mishaps in this way:

> 1. **Class A Mishap.** The resulting total cost of damages to DoD or non-DoD property in an amount of $1 million or more; a DoD aircraft is destroyed; or an injury and/or occupational illness result in a fatality or permanent total disability.
>
> 2. **Class B Mishap.** The resulting total cost of damages to DoD or non-DoD property is $200,000 or more, but less than $1 million. An injury and/or occupational illness result in permanent partial disability or when three or more personnel are hospitalized for inpatient care (beyond observation) as a result of a single mishap.

3. **Class C Mishap.** The resulting total cost of damages to DoD or non-DoD property is $20,000 or more, but less than $200,000; a nonfatal injury that causes any loss of time from work beyond the day or shift on which it occurred; or a nonfatal occupational illness that causes loss of time from work or disability at any time (OPNAVINST 5102.1D, 2005, p. 2-1).

OPNAVINST 5102.1D requires investigation and reporting of all Class A, B, and C mishaps. It does not define a Class D mishap. Based on the definitions listed above, a Class D mishap could be defined as an incident that resulted in less than $20,000 of damages or in a nonfatal injury that did not cause any loss of time from work beyond the day or shift on which it occurred. The OPNAVINST also directs that “near mishaps should be investigated and reported via a HAZREP [Navy message]” (OPNAVINST 5102.1D, 2005, p. 1-12). The mishap reporting matrix specifically directs a hazard report for cases of “Electrical shock afloat from a design deficiency (no injury)” and “Man-overboard mishap underway with no injury” (OPNAVINST 5102.1D, 2005, p. 5-8). The OPNAVINST provides discretion to unit commanding officers on whether or not to report Class D mishaps and near misses.

2. Status of Resources and Training System (SORTS) Reports

Each U.S. Navy ship submits a monthly SORTS report. It contains five columns for reported status: overall status, personnel status, equipment condition status, supply/equipment status, and training status. Each reported status ranges from best, (Category One or C-1), to worst, (Category Five or C-5). The following excerpt from Commander, Military Sealift Command Instruction (COMMSCINST) 3501.2B (1998) defines each of the levels for the overall category.

5.4.1 Category Levels Defined

The overall unit category level will be based only upon organic resources and training under the operational control of the reporting unit or its parent unit. The five categories of overall unit category levels are:

a. C-1. Unit possesses the required resources and is trained to undertake the full wartime mission for which it is organized or designed.

b. C-2. Unit possesses the resources and has accomplished the training necessary to undertake the bulk of wartime mission for which it is organized or designed.

c. C-3. Unit possesses the resources and has accomplished the training necessary to undertake major portions of the wartime mission for which it is organized or designed.

d. C-4. Unit requires additional resources and/or training to undertake its wartime mission, but if the situation dictates, it may be directed to undertake portions of its wartime mission with resources on hand.

e. C-5. Unit is undergoing a service-directed resource change and is not prepared, at this time, to undertake the wartime mission for which it is organized or designed. C-5 units are restricted to:

(1) Ship in overhaul or restricted availability for 30 days or longer.

(2) Units undergoing major equipment conversion/ transition.

(3) Units placed in cadre status by the parent service.

(4) Units being activated, inactivated and reactivated.

(5) Units not manned or equipped but required in the wartime force structure.

(6) Units tasked as training units that could be tasked to perform a wartime mission.

5.4.2 Category Levels, Caveats

The overall unit category level will be identical to the lowest level [highest number] recorded in any of the unit's individually measured resource areas of personnel, equipment and supplies on hand, equipment condition and training, unless subjectively raised or lowered by the unit commander. However, modification of a unit's

> overall level by its commander does not permit modification of the computed status of each individually measured area, which must be reported without adjustment. (COMSCINST 3501.2B, 1988, pp. 15-16)

All U.S. Navy ships undergo overhaul and maintenance from time to time. We wanted to focus the model for this thesis on only those months in which ships were in operational status. However, it was not possible to determine exactly when a ship was in a scheduled maintenance period. Based on the definitions of the overall category, some ship scheduling information can be derived from the SORTS report. Therefore, those months when a ship reported a C-5 rating were attributed to planned maintenance activities, rather than lack of manning, insufficient training, or equipment malfunctions.

III. APPROACH

A. OVERVIEW

The initial version of the TST, developed by NPS's Office of Continuous Learning (OCL) and based on the model proposed by Miller and Shattuck (2007), had 22 user-defined correlations. The four predictor variables were manpower, personnel, training, and HFE. The user defined the interactions of these four inputs with each other, and with the acquisition variables of cost, schedule, performance, and risk. Since it was not possible to obtain sufficient data on all variables of interest, this thesis used manning, SORTS, and mishap data to test whether there were relationships among the variables that were available.

Section B identifies the variables tested in this thesis. Section C states the hypotheses tested. To test the model, data were collected on the U.S. Navy's Oliver Hazard Perry Class Frigate (FFG-7). Section D provides background information on the FFG-7 class. Section E details the process used to collect the data. Section F describes how the obtained data were cleaned and prepared for analysis. Section G describes how the data were used to quantify each variable.

B. VARIABLE DEFINITION

The predictor variable analyzed in this thesis was manning level.

The outcome variables analyzed in this thesis were performance (SORTS) and safety (mishaps).

Variables for which insufficient data were obtained (e.g., personnel and training) and those not applicable to this system (e.g., acquisition schedule), were not investigated in this thesis. Limiting the data collection to the FFG-7 class was an attempt to hold other variables, such as HFE, constant. Data sources and information gathered on some of the controlled variables (e.g., manning cost) are discussed in Chapter VI, under improvements to HSI data.

C. HYPOTHESES

The purpose of this thesis is to use historical data to explore the nature of the relationships that are embedded in an existing notional model of HSI. Only those relationships for which there were appropriate and sufficient data were analyzed. The hypothesized relationships are:

- There is a negative relationship between manning and SORTS levels (i.e., as manning increases, performance as measured on SORTS will improve).
- There is a negative relationship between manning and mishaps (i.e., as manning levels go down, mishaps will increase).
- There is a positive relationship between mishaps and SORTS levels (i.e., as mishaps increase, performance as measured on SORTS will decrease).

D. USN FRIGATE OVERVIEW

The scope of this thesis depended on two major decisions. The first decision was which class of naval platforms to evaluate. The Navy fact files at http://www.navy.mil/navydata/fact.asp provide basic information on aircraft and ship types. As discussed in Chapter I, this thesis focused on the Navy “long hull” Frigate FFG-7 class. The second decision was the time period for the data request. The United States Navy commissioned the last ship of the class, the USS Ingraham, (FFG-61), in August 1989; thus, the initial requests were for data from October 1989 to October 2006. This time period was later reduced to October 1994 through September 2006, due to lack of available data. The end result was 96 months of data for each of the 30 U.S. Navy Frigates active at the time.

Bath Iron Works and Todd Shipyards built 55 FFG-7 class ships in two major variants. The United States Navy received 51 and the Australian Navy received four of these ships. The “short” class was 445 feet long. The “long”

class was 453 feet long (FAS, 2000). A list of commissioning and decommissioning dates for all Navy Frigates was created, based on information from two private Websites: the "Unofficial U.S. Navy Site" at http://navysite.de/frigates.htm and "Federation of American Scientists, Military Analysis Network" at http://www.fas.org/man/dod-101/sys/ship/ffg-7.htm. The list of decommissioning dates was compared to the official Navy FFG fact sheet Website at http://www.navy.mil/navydata/fact_display.asp?cid=4200&tid=1300&ct=4. The Navy fact sheet does not include decommissioning dates, but the list of decommissioned ships corresponds to all of the "short" class FFGs. All of the "long" class FFGs are listed as currently active. The Naval Manpower Analysis Center (NAVMAC) and the FFG Class Squadron (CLASSRON) confirmed this information and provided a list of Unit Identification Codes (UICs) for each active FFG.

E. DATA COMPILATION METHOD

This section describes the process used to collect the data. Locations of contact information are described, rather than using specific names, phone numbers, and e-mail addresses. This was done for two reasons: military personnel change jobs frequently and it aids the research performed on various Navy platforms.

1. Homeports

The homeport of each active FFG is on the official Navy FFG fact sheet Website at http://www.navy.mil/navydata/fact_display.asp?cid=4200&tid=1300&ct=4www.navy.mil. As of November 2008, this Website was last updated in October 2007. The locations of the 30 ships are discussed in Chapter IV, Results.

2. Unit Identification Codes (UICs)

A listing of FFG UICs was necessary to obtain the manning and SORTS data. The FFG Class Squadron (CLASSRON) did not have historical manning or SORTS data, but provided a list of UICs for all active duty FFGs.

The initial contact with the FFG CLASSRON was by telephone. The administrative department of Commander, Naval Surface Forces, Pacific (CNSP) provided the phone number. Subsequent communications were conducted via e-mail. The CLASSRON for FFGs is Destroyer Squadron 14 out of Mayport, Florida. Contact phone numbers are located on the bottom of the “Command” page of their homepage at http://www.cds14.surfor.navy.mil/default.aspx.

To find contact information for other Navy ship classes, the Commander, Naval Surface Forces, Pacific Website contains a page of all Surface Navy CLASSRONs at http://www.surfpac.navy.mil/site%20pages/classrons.aspx. This page contains lists of links to the homepage of each ship, within each CLASSRON. The CNSP Website does not have links to the CLASSRON’s homepages. The administrative department of CNSP may have phone numbers for different CLASSRONs. Commander Navy Surface Forces, Pacific (CNSP) lists their phone number on their homepage at http://www.surfpac.navy.mil/default.aspx.

3. Authorized Manning Level

The Naval Manpower Analysis Center (NAVMAC) did not have historic manning or SORTS data, but provided three “Ship Manpower Document” (SMD) reports. The most recent SMD was prepared in January 2004, and is currently under revision by NAVMAC. The other SMD reports were prepared in December 1997 and September 1999. The reports detail every authorized billet by department, division, rank, rate, officer designator, Navy Enlisted Classification

(NEC) code, and officer subspecialty code. This allowed for the calculation of percent of manning compared to authorized billets, compensating for changes in the authorized levels over time.

The initial contact with NAVMAC was by telephone. Subsequent communications were conducted via e-mail. The Navy Personnel Command (NPC) customer service line provided NAVMAC's phone number. NPC's toll-free customer service number is located on the NPC homepage at http://www.npc.navy.mil/Channels/.

4. Manning Cost

The Chief of Naval Operations Programming Division, N80, provided the Active Duty Programming Rates for FY 2008 by e-mail. Contact information is published in the "OPNAV Planning, Programming, Budgeting and Execution (PPBE) and Program Budget Information System (PBIS) Courses for Fiscal Year 2009 memorandum," which is posted on the N8 homepage under "N8 Hot Topics (Public)" (https://ucstcdom03.ahf.nmci.navy.mil/n8/webbas01.nsf/(vwwebpage)/home.htm?OpenDocument). Alternative cost measures are discussed in Chapter V, under recommendations for future research.

5. Safety Mishap Data

The initial contact with the Naval Safety Center was by telephone. The Naval Safety Center, Afloat, Surface Warfare Division Website, at http://www.safetycenter.navy.mil/afloat/surface/index.asp, lists the Division Head's phone number. Subsequent communications were via phone and e-mail, with e-mail being the primary method.

The Naval Safety Center provided an unclassified Microsoft Excel 2003 document by e-mail. The Excel table gave the date and description of all mishaps onboard Navy FFGs, from FY 1998 through FY 2006. The columns of the data included Event Serial Number, Ship UIC, fiscal year, calendar year and month, and mishap class (A, B, C, or D). These data were used as a measure of safety.

6. Manning and Personnel Data

The manning, personnel, and SORTS report data were obtained from the Defense Manpower Data Center (DMDC) via their online Data Request System (DRS) at https://www.dmdc.osd.mil/drs/. The initial request was for all Enlisted Data Verification Report (EDVR) and SORTS reports on a monthly basis from October 1989 to October 2006 for all Navy FFGs. Following the online submission, DMDC made contact via e-mail and requested phone contact to clarify the request. They required a list of UICs to access the data requested. Due to the nature of the request, it was split in two datasets (one unclassified and one classified), and completed by two different DMDC workers.

DMDC provided unclassified monthly manning and personnel data from October 1994 to June 2008, in a comma separated text file. The DMDC database did not have monthly manning data prior to October 1994. The file contained six columns: date (YYMM format); rank (E01-E09, W01-W05, O01-O09 format), rating, (two to four letters for enlisted ratings, plus four-digit NEC code, if applicable, and four-digit code for officer designators), years of service, ship UIC, and count (number of people with that set of qualities). The file contained 905,323 rows of data. In most cases, there was only one person on board the ship that month with the exact same combination of rank, rate/NEC, and years of service. However, some categories, such as undesignated E01s with less than one year of service, had as many as 12 individuals with the same characteristics, which is why there was an average of 184 rows of manning and personnel data per ship, per month.

7. Performance Data

DMDC provided the SORTS data, classified SECRET, from January 1989 through September 2006 via secure e-mail. The Microsoft Excel 2003 document had 12 columns including year (four-digit format), month (two-digit format), component (active or reserve), and UIC. It also contained five columns of that month's reported status: overall status, personnel status, equipment condition

status, supply/equipment status, and training status. As discussed in the literature review, each reported status is inverted in order of performance and ranges from Category One (C-1), best, to Category Five (C-5), worst performance.

F. DATA CLEANING

We obtained three and created two separate sets of data for each ship, for each month, which were merged to create one data table. All of the obtained data files contained missing data and duplicate entries. This section describes how each of the data tables was cleaned or created. The manning and personnel data set started as a comma separated text file. The other data sets provided or created were Microsoft Excel 2003 files. Unless otherwise noted, all of the cleaning and analysis was done with the statistical software program JMP® version 7.0.2 (SAS Institute Inc., 2007). JMP can import a wide range of files, including comma separated text files and Microsoft Excel files.

1. Homeport Data Table Creation

The UIC list was amended by hand with Homeport and Region columns. This allowed for exploration of possible clustering of the data.

2. Mishap Data Cleaning

Some mishaps involved more than one “Mishap Type” category, e.g., “impact with object” and “flooding” may have occurred in the same mishap and would have created two row entries for one Mishap Serial Number. Since the “Mishap Type” and the event description columns were not of interest for this thesis, these two columns were deleted. Next, the duplicate rows were deleted. This prevented duplicate counting of mishaps when the data were summed by month and ship.

3. Manning Data Set Cleaning

An exploratory pivot table of the Manning data for one ship in Microsoft Excel 2003 returned unreasonably large numbers: for total ship manning: over 400 crewmembers for eight consecutive months. Clicking on one of the suspect cells in the pivot table generated a new spreadsheet with a copy of the source data. Sorting the data by Rate/NEC, then by years of service, revealed a pattern that suggested rows containing 000 or E00 in the rank field, which represented missing data, were duplicate entries. Nearly 46,000 out of over 905,000 lines of the Manning data appeared to be duplicates. These suspect rows were excluded from subsequent data analysis.

4. Authorized Manning and Personnel Table Creation

A table of the authorized manning and personnel levels was created by hand. The first column contained the list of the 96 months of the final data set, October 1998 to September 2006. The next four columns contained the "organizational manpower requirements" summary for that month from the applicable SMD obtained from NAVMAC. Table 1 shows a condensed version of the authorized manning table.

Table 1. Historical Navy FFG Authorized Manning Levels

Time Period	Officer	CPO	Enlisted	Total
Oct 1998 to Sep 1999	16	17	188	221
Oct 1999 to Jan 2004	17	19	198	234
Feb 2004 to Oct 2006	17	17	181	215

In December 1997, the authorized crew level was 16 officers, 17 Chief Petty Officers (CPOs) and 188 "other enlisted," for a total crew size of 221 individuals. In September 1999, the authorized crew was 17 Officers, 19 CPOs, and 198 other enlisted, for a total crew of 234 individuals. In February 2004, the

authorized crew size was reduced to 17 officers, 17 CPOs, and 171 other enlisted, for a total crew of 215 individuals. Section G.2 of this chapter discusses the 2004 reduction in crew size.

5. Status of Readiness and Training System (SORTS) Data Cleaning

An exploratory pivot table of the raw SORTS data in Microsoft Excel 2003 identified three possible issues. The table defined the Row inputs as Year and Month, the Column inputs as UIC, and the intersections as the “overall” report. The first issue raised was that the data set contained numerous holes, or missing entries. The second issue was that the data set did not contain any entries for a few months; that is, there were no data for any of the ships. The third issue was that some entries in the table were between 6 and 10, yet the raw data did not have any values above 5. Sorting the data by year, then by month, then by UIC uncovered nearly four dozen duplicate entries. The duplicate entries were excluded from the data analysis.

G. DEFINITIONS OF PREDICTOR AND OUTCOME VARIABLES

This section describes how the variables were quantified, using the data obtained. It is neither inclusive nor exhaustive of data sources or assessment methods. Due to data limitations, the time period analyzed was trimmed to October 1998 through September 2006.

Eight fiscal years (FYs), or 96 months of data on 30 ships, produced 2,880 rows in the final table. Since all of the three data tables contained missing entries, a two-column table was created in Excel and imported into JMP. This 2,880-row table contained every unique combination of dates and UICs. Then we merged the 2,880 table with each of the other data tables using JMP. By including nonmatches, JMP inserted rows of missing data as applicable.

1. Manning

Manning is the total number of people assigned to the ship for a given month and was used as a substitute for manpower. Manpower is the number of work hours that can be performed by the assigned crew. Due to changes in authorized manning levels, this thesis quantified manning as the percent of total authorized crew assigned to a ship for that month. The cleaned manning data set for October 1998 to October 2006 contained 497,489 rows. This data table was joined with the authorized manning data table. Summing by UIC and date produced one row per month, per ship. The summed data table had 30 missing values, resulting in 2,850 rows.

2. Human Factors Engineering (HFE), Habitability, and Survivability

It was beyond the scope of the current study to obtain HFE, habitability, or system survivability data. However, since all ships were from the “long” FFG-7 class, they are assumed to have similar physical configurations. This study did not obtain detailed data on ship alterations and modifications.

Open source information and the reduction of authorized manning by 2 CPOs and 17 junior enlisted in the January 2004 Ships Manning Document imply that all 30 of the Navy’s FFG-7s underwent major ship alterations in 2003. The “Unofficial U.S. Navy site” states, “in 2003, the Navy started to remove the Mk-13 guided missile launchers from the remaining [FFG-7 Oliver Hazard] PERRY class frigates” (Doehring, n.d.). This concurs with the information on the “Destroyer History” Webpage that,

> 2003 was a significant year for the [FFG-7 Class] Perrys in the US Navy. Raytheon terminated support for the obsolete SM-1MR missile. [The US Navy] embarked on a program not only to remove the missile launchers from the 30 long-hull ships but to modernize them, reducing their cost of operation and extending their service lives to up to 40 years. (Destroyer History Foundation, 2008)

Despite still referring to them as “guided missile frigates,” the “Official Navy FFG fact file” sheet does not mention the ships ever having had a missile launcher. “The guided missile frigates (FFG) bring a short range anti-air warfare (AAW) capability (provided by their Phalanx Close-In Weapon System) to the frigate mission” (U.S. Navy, 2007).

3. Safety

Safety was quantified as the number and frequency of mishaps onboard U.S. Navy Frigates. As discussed in the literature review, reports are not required for most Class D mishaps. Based on this and preliminary data analysis, safety was quantified both with and without Class D events.

Six safety variables were calculated: number of each class, total reportable mishaps (Class A, B, and C), and total number of mishaps (Class A, B, C, and D). The safety data table was transformed using the same method as the manning data table. This resulted in a data table with 329 rows. It was merged with the 2,880 table to align the entries to the other data tables, based on ship UIC and month. Since ships do not file monthly negative reports, it is not possible to know if any Class A, B, or C reports are missing from this data set.

4. Performance

This thesis quantified performance as the SORTS reported levels. Five SORTS variables were provided: overall status, personnel status, equipment condition status, supply/equipment status, and training status. As discussed previously, SORTS levels are low when performance is high, i.e., a ‘1’ on SORTS corresponds to the maximum rating of performance. Merging the SORTS data table with the 2,880 table filled in approximately 400 missing rows.

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IV. RESULTS

This chapter is divided into three sections. The first section is descriptive statistics, the second section is the correlation analysis, and the third section is an analysis of manning and mishap rankings across all ships. Three data tables (manning, safety, and SORTS) were merged into a single data table (described in Table 2). The columns of date and UIC were used to align the data. The data set contained 2880 rows, one for each ship for each month, with 17 columns per row.

Table 2. Variables in Data Set

- Date (month and year)
- UIC (e.g., N21032)
- Component (active or reserve)
- Ship location
    - Homeport (City and State)
    - Region (e.g., East Coast)
- SORTS scores (1 to 5)
    - Overall
    - P, (personnel)
    - R, (equipment)
    - S, (supplies)
    - T, (training)
- Mishaps (counts)
    - Class A
    - Class B
    - Class C
    - Class D
    - Class A-C
    - Class A-D
- Percent total manning

The date and manning data were encoded as continuous variables in JMP. All other variables were encoded as ordinal or categorical data.

A. DESCRIPTIVE STATISTICS

1. Component

Of the 30 ships, the SORTS data identified one ship as belonging to the U.S. Navy Reserve (USNR) and the rest of the ships as active component (USN).

2. Homeports

The Navy's FFGs operate out of six homeports. The largest concentration is in Mayport, Florida, with 12 ships. Combined with the six FFGs stationed in Norfolk, Virginia, there are 18 FFGs stationed on the East Coast of the United States. San Diego, California, has five FFGs, and Everett, Washington, has three FFGs, for a total of eight FFGs on the West Coast. Pearl Harbor, Hawaii and Yokosuka, Japan both have two FFGs, for a total of four FFGs outside the continental United States (OCONUS). Table 3 lists the number of ships by homeport and region.

Table 3. Navy FFGs by Homeport and Region

HOME PORT		# of Ships	REGION	# of Ships
Mayport	FL	12	East	18
Norfolk	VA	6	Coast	
San Diego	CA	5	West	8
Everett	WA	3	Coast	
Pearl Harbor	HI	2	OCONUS	4
Yokosuka	Japan	2		

3. SORTS Report

The descriptive statistics of the SORTS reports, classified as SECRET, are not included in this thesis pending final determination of classification. No significant relationships were found between any of the SORTS scores and any of the other variables.

4. Mishap Report Rates

Table 4 shows the descriptive statistics for the mishap reports for all 30 ships over 96 months. The monthly rates are average mishap rates per ship per month. The number of mishaps reported by any ship over the 96 months ranged from three to 32; the average number of mishaps was 14.17 while the most common number of reported mishaps was 12. Table 4 includes statistics for the subtotal of all reportable mishaps (Class A, B and C). As mentioned in Chapter II, Literature Review, reporting of Class D mishaps is optional.

Table 4. Mishap Statistics Per Ship Over Eight FYs

	Minimum	**Maximum**	**Average**	**Std Dev**	**Mode**	**Total**	**Monthly Rate**
Class A	0	1	0.20	0.41	0	6	0.0021
Class B	0	2	0.53	0.73	0	16	0.0056
Class C	1	13	5.50	3.10	8	165	0.0573
Class D	1	24	7.93	6.13	8	238	0.0826
Class A-C	1	14	6.23	3.30	5	187	0.0649
Class A-D	3	32	14.17	6.70	12	425	0.1476

5. Manning

Figure 5 shows the percent manning over the 96 months for each of the 30 ships. The manning level for any ship for any month ranged from 42.74% to 121.40% with the mean manning level at 92.72% and median of 94.87%.

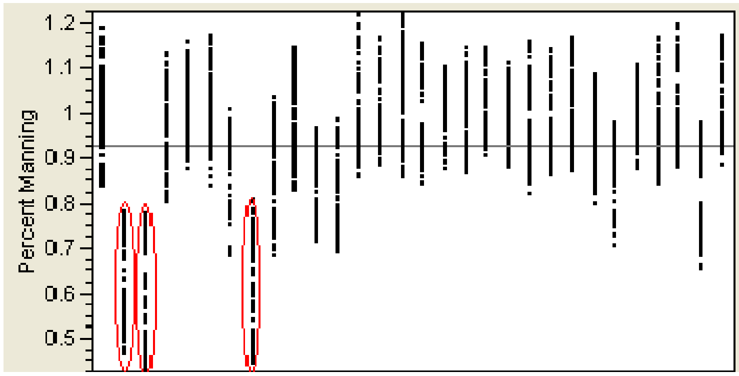

Figure 5. Percent Manning By UIC for All 30 Ships

The three ships circled in red Figure 5 have significantly lower manning levels than the other 27 ships. One of the three ships was confirmed to be Reserve Component while the other two are suspected to be Reserve Component. These three ships were determined to be sufficiently different from the others and, therefore, were excluded from further analysis.

Figure 6 shows the percent manning over the 96 months for each of the 27 ships believed to be active component. The manning level for any ship for any month ranged from 64.96% to 121.40% with a mean manning level of 96.28% and a median of 95.93%.

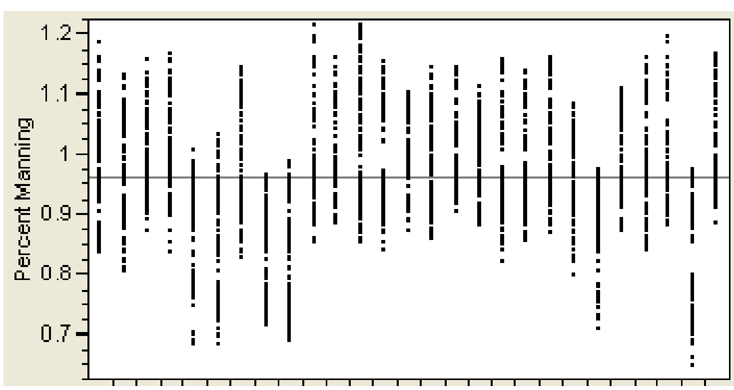

Figure 6. Percent Manning by UIC for 27 Ships

B. CORRELATION MATRIX

A matrix of Pearson correlations for percent manning and the six safety variables (Classes A, B, C, D, Class A through C and Class A through D) was calculated in Microsoft Excel for the 27 ships in the study sample. Table 5 shows this correlation matrix. Another version of this matrix, including additional exploratory variables, is in Appendix A. All of the correlations in Table 5 were statistically significant at the 0.05 level. Not surprisingly, the correlations between several of the mishap classes is fairly high. Of interest to this thesis is the relationship between manning and mishaps.

Table 5. Correlation Matrix

	Class A	Class B	Class C	Class D	Class A-C	Class A-D
Percent Manning	0.0005	0.0062	0.0295	0.0253	0.0295	0.0372
Class A	1.0000	-0.0035	0.0485	0.0102	0.2106	0.1327
Class B		1.0000	0.0038	-0.0165	0.2557	0.1385
Class C			1.0000	0.0488	0.9534	0.6025
Class D				1.0000	0.0436	0.8064
Class A-C					1.0000	0.6260

C. ANALYSIS OF RELATIVE RANKING BY SHIP

To explore general trends in manning and mishaps, all of the ships were ranked from 1 (best), to 27 (worst), for each month of the study period based on percent of total manning and number of reportable mishaps. The ship with the highest percent manning for a month was assigned a manning rank of 1 while the ship with the lowest percent manning for a given month was assigned a rank of 27. The ship with the most reportable mishaps for a month was assigned a mishap rank of 27. If a ship did not have any mishaps for a month it was assigned a mishap rank of 0, (i.e. if only three ships reported mishaps for a

month, then the top 24 ships were all assigned the mishap rank of 0 and the other three were assigned mishap ranks of 25, 26 and 27). Table 6 shows the results of averaging each of the two ranks over the 96 months then ranking the ships again based on their averages. The column on the left is the average of the average manning and average mishap ranks over 96 months for each ship. The right three columns are the corresponding averages converting into a rank from 1 to 27. The rows are sorted from lowest average overall rank to highest average overall rank. The three highest ranks are in bold and the three lowest ranks are underlined and in bold.

Overall Average	Average Manning	Average Mishap	Overall Rank	Manning Rank	Mishap Rank
3.0573	5.5625	0.5521	**1**	**1**	**3**
3.8073	5.6667	1.9479	**2**	**2**	22
4.4844	7.8750	1.0938	**3**	**3**	10
5.3125	9.2708	1.3542	4	4	13
5.3542	10.4271	0.2813	5	5	**2**
5.8906	10.6979	1.0833	6	6	9
6.2604	10.8646	1.6563	7	7	17
6.5990	11.2292	1.9688	8	8	23
6.6354	12.1667	1.1042	9	9	12
6.8490	12.3229	1.3750	10	10	14
6.9479	12.8438	1.0521	11	11	6
7.5781	14.0833	1.0729	12	12	8
8.1563	14.6354	1.6771	13	13	19
8.2396	16.2188	0.2604	14	18	**1**
8.3594	16.1667	0.5521	15	17	4
8.4219	16.0104	0.8333	16	15	5
8.5104	15.9271	1.0938	17	14	11
8.8594	16.0938	1.6250	18	16	16
9.2135	17.3750	1.0521	19	22	7
9.2917	17.1979	1.3854	20	20	15
9.4688	17.0104	1.9271	21	19	20
9.6667	17.3958	1.9375	22	23	21
9.6979	17.2396	2.1563	23	21	24
10.2813	17.8125	2.7500	24	<u>**25**</u>	<u>**26**</u>
10.3906	17.5313	3.2500	<u>**25**</u>	24	<u>**27**</u>
10.4531	19.2500	1.6563	<u>**26**</u>	<u>**27**</u>	18
10.9219	19.1250	2.7188	<u>**27**</u>	<u>**26**</u>	<u>**25**</u>

Table 6. Relative Ranking of Ships by Manning and Mishaps

As is evident in Table 6, ships with low overall ranks tend to have both relatively low manning levels and relatively high mishap rates.

Figure 7 compares manning rank over time with the mishap rank over time for the ships with the two highest and two lowest overall ranks. Figure 8 shows the same data for only two ships: the highest and lowest in ranking. Figures 7 and 8 demonstrate that manning ranks for all of the ships varied over time. No ship was consistently ranked high or low over the entire 96 months.

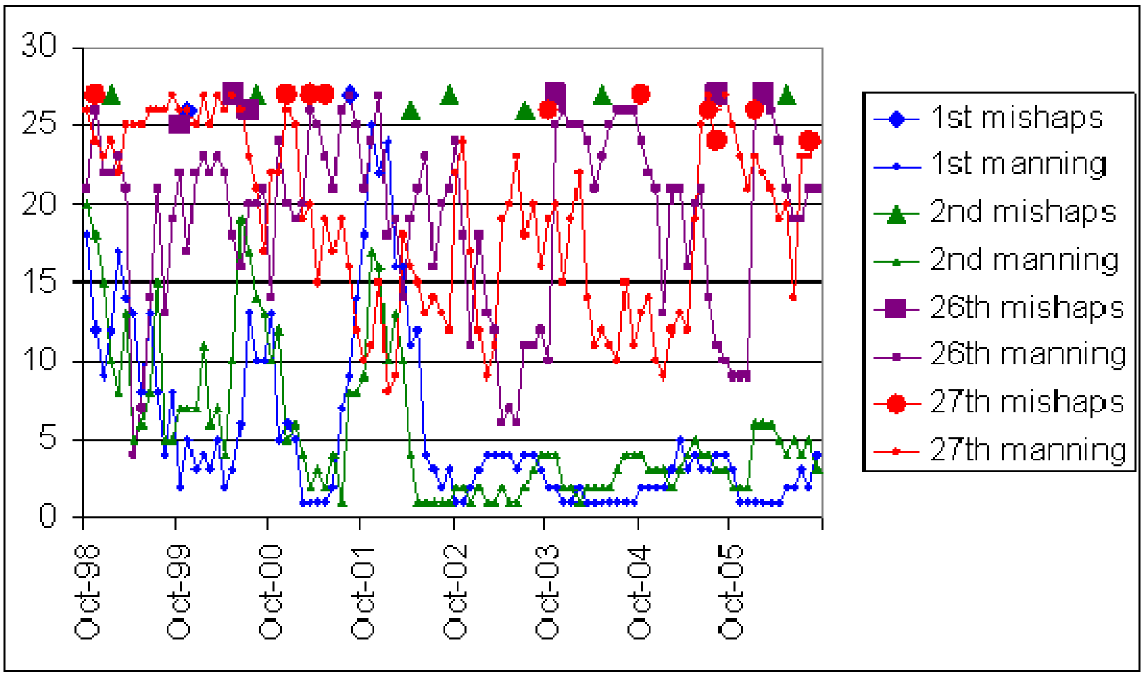

Figure 7. Manning and Mishap Rankings Over 96 Months for the Top Two and Bottom Two Overall Ranked Ships.

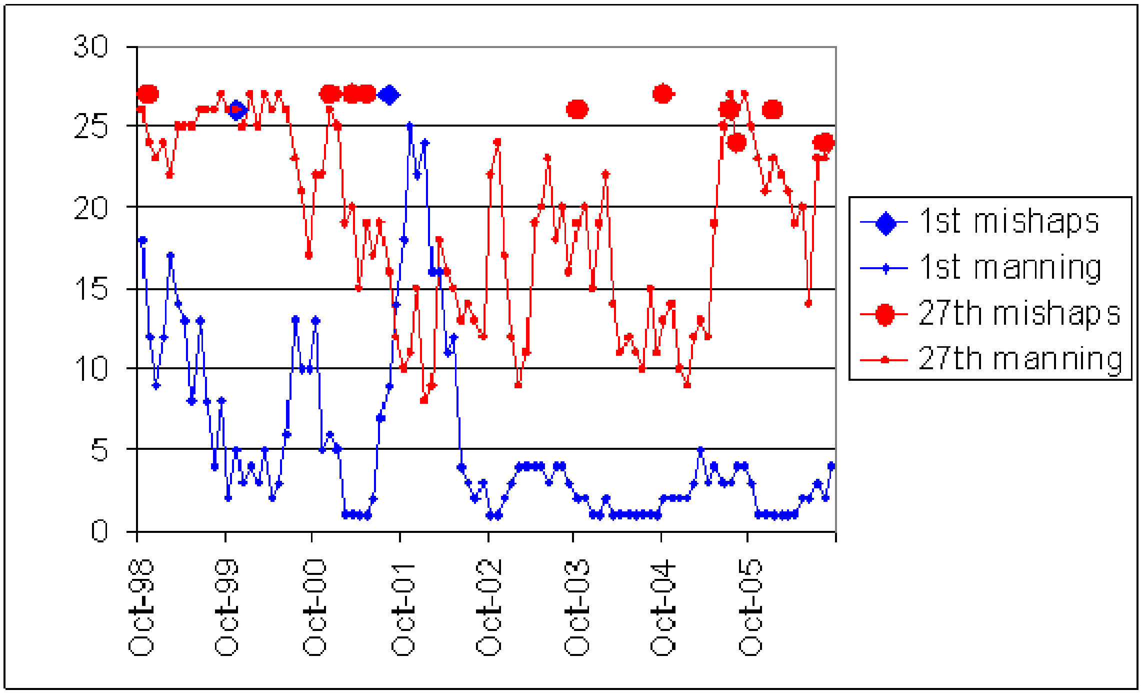

Figure 8. Manning and Mishap Rankings Over 96 Months for The Top and Bottom Overall Ranked Ships.

To determine whether relative ranking in manning level is independent of mishap rankings, a nonparametric correlation was performed in JMP. The manning rank and mishap rank columns in Table 6 were compared using Spearman's rho. The variables were positively correlated (Spearman's rho = 0.4194, p-value = 0.0294). This finding shows that there is a positive relationship between a ship's average manning rank and its average mishap rank over the 96 months. In other words, there is an indication of a negative relationship between manning levels and mishap rates. Mishap rates increase as manning levels drop.

V. DISCUSSION

The first section of this chapter discusses the three hypotheses based on the results reported in the previous chapter. The second section lists the conclusions drawn from the analysis of relative rankings. The third section discusses the implications of the results with respect to the NPS HSI TST computer program.

A. HYPOTHESES

1. Hypothesis One, Manning and Performance

The results failed to support hypothesis one, that there is a positive relationship between manning and SORTS levels. There were no significant relationships between percent manning and any of the five SORTS reports.

2. Hypothesis Two, Manning and Safety

The results of the rankings in Table 6 support hypothesis two, that there is a negative relationship between manning and mishaps. There was a statistically significant negative correlation between manning levels and mishap rates. Ships that have relatively low percent manning levels also have lower mishap ranks, which corresponds to higher rates of mishaps.

3. Hypothesis Three, Safety and Performance

The results failed to support hypothesis three, that there is a negative relationship between SORTS levels and mishaps. There were no statistically significant relationships between any of the eight safety variables and any of the five SORTS report variables.

B. MANNING AND MISHAPS

Reportable mishaps (those involving serious injury or damages over $20,000) appear to be rare. This is good news for the U.S. Navy but provides a small data set for analysis. The analysis of relative rankings by ship found a statistically significant negative relationship between percent manning and mishap rates. The results of this thesis support the idea that there is a negative relationship between manning levels and mishap rates, but we suggest that more detailed research is needed to isolate this relationship from numerous other influences and any noise that may be present in the data set. This is discussed more in Chapter VI, Conclusion and Recommendations.

C. IMPLICATIONS FOR NPS HSI TST MODEL

This thesis investigated two of the 22 relationships in the NPS HSI TST program. We found a statistically significant relationship between manning levels and mishap rates. However, the analysis of ranking did not derive an equation to estimate mishap rates based on percent of manning. The average rate of reportable mishaps (Class A, B and C) calculated from the safety data provided is 0.06 mishaps per ship per month. If, for example, the mishap rate for USN FFGs is not significantly influenced by the HFE level, then the average rate can be used to define the relationship between HFE and Safety in the NPS HSI TST. However, defining the mishap rate as a constant would make it irrelevant in tradeoff analysis.

Although this was not pursued, the personnel costs provided by N80, $59,139 per year per enlisted and $123,269 per year per officer, could be used to define the relationships of cost with manpower and personnel.

VI. CONCLUSION AND RECOMMENDATIONS

The first section of this chapter discusses how finding no significant relationship between many of the variables can justify a reduced sample size for future studies. The second section suggests ways to improve the data collection and analysis methods for each of the HSI domains. The third section suggests two possible directions to expand data collection beyond USN FFGs. The fourth section restates the implications of the results of this thesis.

A. CONSISTENCY

No practically significant differences were found in manning, personnel, performance or safety based on date, ships, homeport, or region. For example, there is no evidence that ships in Hawaii are more likely to report a class D mishap than ships in Norfolk, Virginia. This means that data collected on a sample of ships should be applicable to all Navy Frigates. However, there were significant differences in manning levels between one ship that was classified as a Navy Reserve ship in the SORTS data and 29 of the ships classified as Navy Active component. Two additional ships in the sample appeared to be Navy Reserve ships. The low manning level for these three ships may be due to exclusion of activated U.S. Navy Reserve personnel in the database.

B. IMPROVEMENTS TO HSI DATA

This section discusses possible improvements to the types of data collected, and analysis methods utilized, to explore HSI in the U.S. Navy. Future research may benefit from more detailed data collection. This thesis chose breadth (eight fiscal years) over depth of data (e.g., average hours spent on watch over one month of underway operations). The data analyzed for this thesis were insufficient to validate all the relationships in the notional trade space tool. However, empirical evidence was found to support a negative relationship between manning and mishap rates. This thesis did not provide substitutes for

missing data. The missing SORTS data could be estimated based on trends for the ship, but this may be less accurate, especially if several reports in a row are missing.

1. Manpower

The historical reports collected by the U.S. Navy do not record manpower data. Therefore, manning was used as a surrogate for manpower. The data collected could not distinguish between a crew that works 40 hours a week (which is a common practice while in port) from a crew that works over 80 hours a week (common on deployments) to maintain an overall SORTS score of Category 1. A better approximation would be to compare actual workload, collected onboard a sampling of ships, with the prescribed workload data contained in the SMDs provided by NAVMAC. A prospective study could be designed to do this type of analysis. Collecting these data retrospectively is virtually impossible. However, past manpower levels could be estimated by collecting and analyzing the following: ship's schedules, typical watch stations manned based on ship's schedule, personnel assigned, and maintenance jobs completed. Other aspects of manpower, such as unit cohesion and morale, could be estimated based on crew turnover rates.

2. Personnel and Training Variables

Eight personnel variables were analyzed but were deemed inadequate to test relationships between personnel and the other HSI domains. The variables were percent of junior enlisted (E01-E06), percent of Chief Petty Officers (CPOs), (E07-E09), percent of officers, percent of personnel with a Navy Enlisted Classification (NEC) code, and four summations of years of service. Chief Warrant Officers (W01-W05) were included in the officer category. Officer designators were evaluated as personnel without an NEC.

This thesis proposed using NECs, rank, and years of service as personnel and training measures. The SMDs provided by NAVMAC and the data provided

by DMDC both included the same rank, rate, and NEC information. One could compare, by billet, the assigned personnel with the authorized personnel list. However, this method was beyond the scope of this thesis. A billet comparison is just one way to measure the personnel and training levels. Additional information sources could include an individual's aptitude test scores at enlistment, grade or class standing at service schools, and advancement exam scores.

3. Training

Based on the data collected, it was not possible to quantify training. Training could be quantified as the activities that increase a unit's level of personnel. In this way, a ship that sends a crewmember to school to obtain an NEC, achieves the same result as a ship that detaches an unqualified person and obtains a new person with the desired NEC. In both cases, the manning level stayed constant, while one measure of personnel increased.

4. Schedule

Schedule, as defined in the program acquisition process, normally only applies to delivery of new systems. Generally, it is not applicable to the evaluation of legacy systems, unless the system is completing a modernization program. Scheduling data, such as operational tempo and unit availability for tasking, is performance related and could be used in similar efforts in the future.

5. Human Factors Engineering

Due to the many similarities within the 'long' FFG class, HFE is difficult to assess within this community. HFE may be more useful for an analysis that includes several different classes (e.g., cruisers, destroyers and frigates). Several methods could test if HFE is a significant factor, to include determining the exact time period around 2003 when each ship had its missile launcher removed and other major upgrades performed. One could also obtain detailed information on every ship alteration and modification, such as the addition of a

new optic system, or upgrades to a computer system. It would be possible to obtain data for the decommissioned ‘short’ FFGs and investigate possible effects between these two distinct categories of ship platforms.

6. Habitability, and Survivability

As mentioned in Chapter III, Section G, this study did not obtain any detailed human factors engineering, habitability or system survivability data. The NPS HSI TST model theorizes that decisions made regarding manpower, personnel, training and HFE determine safety, habitability and system survivability. Just as training changes the level of personnel, changes in HFE impact the level of habitability and survivability. Therefore, any efforts to improve the measure of HFE should improve the measures of habitability and survivability as well.

7. Risk/Safety Variable

The results of this thesis identify safety as the variable that would most benefit from improved data collection and improved analysis. Due in part to the infrequent rate of all mishaps, this thesis did not analyze causal factors for any of the reported mishaps (e.g., mishaps due to heavy seas while underway were not evaluated separately from mishaps during command sponsored sports activities ashore). Board categories, included in the safety data from the Naval Safety Center, could be used to isolate only those mishaps suspected of being caused by manning or training factors. A better approach would be a detailed qualitative analysis of the full written mishap report for each mishap. Including minor injury and illness rates to future studies would increase the volume and sensitivity of safety data collected.

8. Cost Variable

Cost of ownership was not used in the data analysis, but some consideration was given to how to address the cost of a system. It is possible to

quantify manning and personnel costs as the FY 2008 Active Duty Programming Rates of $123,269 per year for officers and $59,139 per year enlisted. This thesis did not collect any cost estimates for training, HFE, acquisition, operations or maintenance.

Developing an accurate method to determine total system cost is a goal worthy of its own study. One challenge in capturing the true cost of any DoD system is in defining the boundaries. In addition to payroll, a ship's costs could include fuel, food, repair parts, shore based maintenance facilities, and medical care. For more information on alternate cost estimation methods see Naval Center for Cost Analysis (NCCA) 'NCCA Cost Tools' webpage at http://www.ncca.navy.mil/services/costtools.cfm.

This thesis recommends quantifying manning and personnel cost as the Active Duty Programming rate for a single fiscal year. An alternative would be to obtain the manpower programming rates for each FY from the Program Budget Information System (PBIS) database or from N80, Programming Division. Separate rates for activated reservists are also available.

9. Performance Variables

All of the performance data used in this thesis were based on the SORTS data reported by each ship. The results of this thesis suggest that the SORTS scores are insensitive to the variables quantified. The SORTS scores are also somewhat subjective and confounded by the independent variables (e.g., if a ship does not have a critical NEC billet filled, it has to report a lower personnel level). Other performance measures that could be included in future studies are externally graded ship exercises, personnel reenlistment rates, time to earn watch station qualifications, operational tempo, and unit availability for tasking.

C. ADDITIONAL APPLICATIONS

The work of this thesis could be expanded to include additional ships that are similar to the USN Frigates, (e.g. Cruisers and Destroyers) to permit greater

pooling of data or it could be expanded to a variety of diverse naval platforms (e.g., amphibious ships, Submarines, or Aircraft Carriers).

D. CONCLUSION

HSI, though required by law, is often confused as just HFE or just SE. There remains a need for shared representations of the HSI trade space to facilitate communication between what are often isolated domains. While the data collected for this thesis were insufficient to validate all the relationships in one notional trade space tool, finding empirical evidence of a negative relationship between manning levels and mishap rates is a substantial step forward. Just as this thesis advanced previous work, further research is needed to develop the NPS HSI Trade Space Tool to maturity.

APPENDIX A. CORRELATION MATRIX

This appendix contains an exploratory correlation matrix of 16 continuous variables from the 25 original variables.

	Class B	Class C	Class D	Class A-C	Class A-D	Percent Junior manning	Percent CPO manning	Percent Officer manning	Percent total manning	Percent with NEC	Junior years of service	CPO years of service	Officer years of service	Total years of service
Class A	*N/S*	0.0485	*N/S*	0.2106	0.1327	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*
Class B	1.0000	*N/S*	*N/S*	0.2557	0.1385	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*
Class C		1.0000	0.0488	**0.9534**	**0.6025**	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	0.0421	*N/S*
Class D			1.0000	0.0436	**0.8064**	*N/S*	0.0402	*N/S*	*N/S*	*N/S*	*N/S*	*0.0310*	*N/S*	*N/S*
Class A-C				1.0000	**0.6260**	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	*N/S*	0.0474	*N/S*
Class A-D					1.0000	*N/S*	0.0558	*N/S*	*N/S*	*N/S*	*N/S*	*0.0441*	*N/S*	*N/S*
Percent Junior manning						1.0000	**0.6659**	0.1430	**0.9851**	-0.2070	**0.5627**	**0.5840**	0.1106	**0.6571**
Percent CPO manning							1.0000	0.1018	**0.7417**	*N/S*	0.3209	**0.9417**	0.0868	**0.5993**
Percent Officer manning								1.0000	0.2681	-0.4511	-0.1737	0.1070	0.5021	-0.0427
Percent total manning									1.0000	-0.2460	0.5064	**0.6602**	0.1767	**0.6483**
Percent with NEC										1.0000	0.1630	*N/S*	-0.1706	0.0894
Junior years of service											1.0000	**0.3907**	*N/S*	**0.9229**
CPO years of service												1.0000	0.0321	**0.6728**
Officer years of service													1.0000	0.0558

Correlation Matrix

bold, r greater than 0.548

N/S, p-value was greater than 0.06

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APPENDIX B. DODI 5000.2 ENCLOSURE 7

E7. ENCLOSURE 7, HUMAN SYSTEMS INTEGRATION (HSI)

E7.1. General. The PM shall have a comprehensive plan for HSI in place early in the acquisition process to optimize total system performance, minimize total ownership costs, and ensure that the system is built to accommodate the characteristics of the user population that will operate, maintain, and support the system. HSI planning shall be summarized in the acquisition strategy and address the following:

E7.1.1. Human Factors Engineering. The PM shall take steps (e.g., contract deliverables and Government/contractor IPT teams) to ensure human factors engineering/cognitive engineering is employed during systems engineering over the life of the program to provide for effective human-machine interfaces and to meet HSI requirements. Where practicable and cost effective, system designs shall minimize or eliminate system characteristics that require excessive cognitive, physical, or sensory skills; entail extensive training or workload-intensive tasks; result in mission-critical errors; or produce safety or health hazards.

E7.1.2. Personnel. The PM shall work with the personnel community to define the human performance characteristics of the user population based on the system description, projected characteristics of target occupational specialties, and recruitment and retention trends. To the extent possible, systems shall not require special cognitive, physical, or sensory skills beyond that found in the specified user population. For those programs that require skill requirements that exceed the knowledge, skills, and abilities of current military occupational specialties or that require additional skill indicators or hard-to-fill military occupational specialties, the PM shall consult with personnel communities to identify readiness, personnel tempo (PERSTEMPO), and funding issues that impact program execution.

E7.1.3. Habitability. The PM shall work with habitability representatives to establish requirements for the physical environment (e.g., adequate space and temperature control) and, if appropriate, requirements for personnel services (e.g., medical and mess) and living conditions (e.g., berthing and personal hygiene) for conditions that have a direct impact on meeting or sustaining system performance or that have such an adverse impact on quality of life and morale that recruitment or retention is degraded.

E7.1.4. Manpower. In advance of contracting for operational support services, the PM shall work with the manpower community to determine the most efficient and cost-effective mix of DoD manpower and contract support. Once the

Manpower Estimate is approved by the DoD Component manpower authority, it shall serve as the authoritative source for reporting manpower in other program documentation.

E7.1.5. Training. The PM shall work with the training community to develop options for individual, collective, and joint training for operators, maintainers and support personnel and, where appropriate, base training decisions on training effectiveness evaluations. The PM shall address major elements of the training system described in DoD Directive 1430.13, reference (bd), and place special emphasis on options that enhance user capabilities, maintain skill proficiencies, and reduce individual and collective training costs. The PM shall develop training system plans to maximize the use of new learning techniques, simulation technology, embedded training, and instrumentation systems that provide anytime, anyplace training and reduce the demand on the training establishment. Where possible, the PM shall maximize the use of simulation-supported embedded training, and the training systems shall fully support and mirror the interoperability of the operational system. For training programs that require training infrastructure modifications, the PM shall identify technology, schedule, and funding issues that impact program execution.

E7.1.6. Environment, Safety and Occupational Health (ESOH). As part of risk reduction, the PM shall prevent ESOH hazards where possible, and shall manage ESOH hazards where they cannot be avoided. The acquisition strategy shall incorporate a summary of the Programmatic ESOH Evaluation (PESHE), including ESOH risks, a strategy for integrating ESOH considerations into the systems engineering process, identification of ESOH responsibilities, a method for tracking progress, and a compliance schedule for NEPA (42 U.S.C. 4321-4370d and Executive Order 12114, references (x) and (az)). During system design, the PM shall document hazardous materials used in the system and plan for the system's demilitarization and disposal. The CAE (or for joint programs, the CAE of the Lead Executive Component) or designee, is the approval authority for system-related NEPA and E.O. 12114 documentation. For acceptance of ESOH mishap risks identified by the program, the CAE is the acceptance authority for high risks, PEO-level for serious risks, and the PM for medium and low risks as defined in the industry standard for system safety.

E7.1.7. Survivability. For systems with missions that might require exposure to combat threats, the PM shall address personnel survivability issues including protection against fratricide, detection, and instantaneous, cumulative, and residual nuclear, biological, and chemical effects; the integrity of the crew compartment; and provisions for rapid egress when the system is severely damaged or destroyed. The PM shall address special equipment or gear needed to sustain crew operations in the operational environment.
Last Modified on: 12/17/2004 (DODI 5000.2, 2004, p. E7).

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